

ES 104 Laboratory # 4

INTRODUCTION TO PLATE TECTONICS

Introduction

The Theory of Plate Tectonics has revolutionized the science of Geology in the last 30 years. The theory states that the outer surface of the earth consists of 7 major lithospheric plates and numerous smaller ones, and these plates move around on a ductile layer referred to as the asthenosphere. The boundaries between the lithospheric plates, which are where they interact with one another, are characterized by distinctive topographic features and catastrophic geologic processes such as earthquakes and volcanism.

Goals and Objectives

- Introduce some of the basic ideas of Plate Tectonics
- Study the Plate Tectonic setting of the western United States and parts of the adjacent Pacific Ocean basin
- Describe the relation between earthquakes, volcanoes, and plate boundaries
- Learn to use map scales to convert map measurements to real-world distances

Name _____ **KEY** _____

Lab day _____ Lab Time _____

Pre-lab Questions – Complete these questions before coming to lab.

Briefly define the following key words, drawing diagrams where necessary, and answer the questions.

1. Lithosphere

RIGID OUTER PORTION OF EARTH THAT INCLUDES THE CRUST AND THE UPPERMOST UPPER MANTLE

2. Asthenosphere

PORTION OF THE UPPER MANTLE BELOW THE LITHOSPHERE THAT IS WEAK (SLUSHY, GOOEY, ETC.)

3. Divergent Plate Boundary

AREA WHERE LITHOSPHERE PLATES ARE MOVING APART. CHARACTERIZED BY RIDGE AND CONSTRUCTION OF LITHOSPHERE BY UPWELLING OF HOT MANTLE MATERIAL TO FILL THE VOID LEFT BY THE DIVERGENCE OF PLATES.

4. Convergent Plate Boundary

AREA WHERE LITHOSPHERIC PLATES ARE MOVING TOWARD ONE ANOTHER. IF AN OCEANIC PLATE IS INVOLVED, THEY ARE CHARACTERIZED BY SUBDUCTION OF AN OCEANIC PLATE, DESTRUCTION OF LITHOSPHERE, AND A DEEP OCEAN TRENCH.

5. Transform Plate Boundary

AREA WHERE LITHOSPHERIC PLATES ARE MOVING PAST ONE ANOTHER. TRANSFORM BOUNDARIES DO NOT HAVE DESTRUCTION OR CONSTRUCTION OF LITHOSPHERE.

6. At what type of plate boundary is Oregon located?

OREGON IS LOCATED AT A CONVERGENT PLATE BOUNDARY.

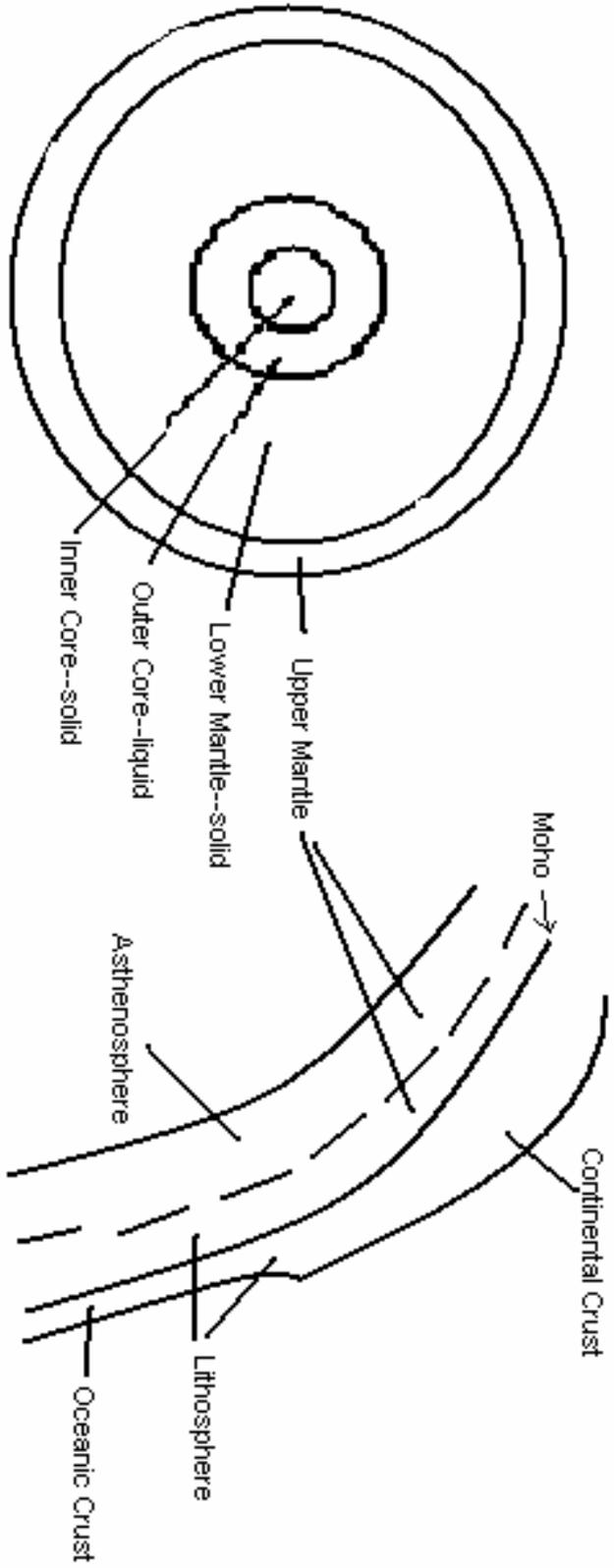
7. What type of plate boundary is found in southern California?

THE SAN ANDREAS FAULT IS A TRANSFORM PLATE BOUNDARY.

8. Sketch a cross-section of the Earth, showing the internal structure.

Include inner core, outer core, lower mantle, upper mantle, asthenosphere, lithosphere, moho, oceanic crust, continental crust (you may need an inset for the relationship of the last few items).

(on next page)



Part A—"The Earth's Fractured Surface" Map

Examine the National Geographic map "The Earth's Fractured Surface", and answer the following questions:

1. What type of crust is present where most divergent plate margins occur?

OCEANIC

2. What areas have groups of active volcanoes?

WEST COAST OF SOUTH AMERICA, INDONESIA, JAPAN, WEST COAST OF NORTH AMERICA, ALEUTIAN ISLAND CHAIN, PHILIPPINES, ICELAND, EAST AFRICAN RIFT

3. If these are associated with plate boundaries, use the term that describes the type of plate boundary.

MOST ARE AT CONVERGENT BOUNDARIES, SOME ARE AT DIVERGENT BOUNDARIES

4. Look at the Pacific Northwest area. What tectonic plates are there or nearby which may affect that area. (There are three.) Describe the type of boundaries that exist between these plates. (One type for each pair of plates.)

NORTH AMERICAN—JUAN DE FUCA IS CONVERGENT
JUAN DE FUCA —PACIFIC IS DIVERGENT
JUAN DE FUCA—GORDA IS TRANSFORM

5. The margin of the Pacific Ocean basin is often referred to as the "Ring of Fire". What evidence is shown on the map to justify this name?

IT IS A ZONE OF ACTIVE VOLCANOES

6. List some areas that have isolated volcanoes.

EAST AUSTRALIA, AUSTRAL-COOK ISLANDS, EASTER ISLAND, JUAN FERNANDEZ ISLAND, KERGUENLEN ISLAND, TIBESTI UPLIFT. ETC.

7. Examine the Hawaiian Islands and surrounding area. Notice the alignment of the Hawaiian Islands and submerged seamounts of the Hawaiian Ridge extending to Midway Island and beyond. This linear string has an abrupt bend, and continues as the Emperor Seamounts to the Aleutian Trench.

- a. What does the yellow circle with the arrow pointing to the northwest represent? (The red triangle in the center is the symbol for an active volcano.) Also record the information this symbol gives about Hawaii.

HOT SPOT, WITH MOTION OF OVERLYING PLATE SHOWN IN IN./YR
PACIFIC PLATE IS MOVING NORTHWEST AT 4.0 IN./YR

- b. How can this information help you understand the formation of the Hawaiian Ridge?

RIDGE WAS CREATED BY VOLCANOES FROM MAGMA AT HOTSPOT.
AS PACIFIC PLATE MOVED NORTHWEST, DRAGGED VOLCANO OFF OF
HOTSPOT AND ANOTHER FORMED IN NEW AREA OF PLATE.

- c. Midway Island is the small island just north and slightly east of the 's' of 'Midway Is.' on the map. The volcanic rocks on Midway Island are 27 million years old. Determine the rate in **inches/year** (rate = distance/time) and direction of plate motion of the Pacific Plate over the last 27 million years. (NOTE: Scale of map: 1 inch = 758 miles. Do not forget to convert miles to inches, and use all the zeroes instead of 'million' years.) Show your calculations with units.

$$2.5in. \times \frac{758mi.}{1in.} = 1895mi. \qquad 1895mi. \times \frac{5280ft.}{1mi.} \times \frac{12in.}{1ft.} = 120,000,000in.$$

$$\frac{120,000,000in.}{27,000,000yr} = 4.4in / yr$$

- d. Compare your calculated value to the map data about plate movement at the Hawaiian hotspot.

VERY SIMILAR 4.0 vs. 4.4 IN/YR

- e. If your toenails grow about 1 mm a month, is the rate of motion of the Pacific Plate comparable to this? (Like compared to how fast you can drive, or walk...)

TOENAILS $\frac{1mm}{1month} \times \frac{1in.}{25.4mm} \times \frac{12months}{1year} = 0.47in / yr$

WALKING $\frac{3mi.}{hr} \times \frac{5280ft}{1mi.} \times \frac{12in.}{1ft} \times \frac{24hr}{1day} \times \frac{365.25days}{1year} = 1.67 \times 10^9 in / yr$

(I COULD WALK A TRILLION INCHES IN A YEAR!! 26,300 MILES!)

- f. Suiko Seamount (which is not labeled on the map) is located approximately beneath the second "R" in the word "EMPEROR", has yielded an age date of 65 million years. Based on the available age data and the distribution of the Hawaiian Islands chain and the Emperor Seamount chain, discuss how the movement of the Pacific Plate has changed direction through time. Is this change in motion consistent with other seamount chains in the Pacific Ocean? Explain.

THERE IS A BEND IN THE HAWAIIAN RIDGE—EMPEROR SEAMOUNT CHAIN BETWEEN SUIKO SEAMOUNT AND MIDWAY ISLAND. THE PACIFIC PLATE WAS MOVING NORTHWARD WHEN SUIKO WAS FORMED, AND STARTED MOVING NORTHWESTWARD SOMETIME BETWEEN 65 MILLION AND 27 MILLION YEARS AGO. OTHER SEAMOUNT CHAINS HAVE SIMILAR BENDS IN THEM.

8. Locate the eruptions listed in "Notable Volcanic Eruptions of the 20th Century" (upper right corner of the chart).
- a. At what type of plate boundary have the vast majority of the volcanic eruptions in the 20th century occurred?

MOST ERUPTIONS HAVE OCCURRED AT CONVERGENT PLATE BOUNDARIES.

- b. Consider the Iceland eruption of 1963. What two factors may have contributed to this eruption?

ICELAND IS LOCATED OVER A HOTSPOT, AND ON AN OCEANIC RIDGE. BOTH WERE FACTORS IN THE ERUPTION OF 1963.

9. Find earthquakes listed in "Notable Earthquakes of the 20th Century". Does there seem to be a relationship between the magnitude of a given earthquake and the type of plate boundary where it occurred? What is this relationship?

THE TOP TEN QUAKES LISTED ALL OCCURRED ON CONVERGENT BOUNDARIES; THE ELEVENTH-LARGEST LISTED OCCURRED ON A TRANSFORM BOUNDARY.

Part B – "Living on the Edge" Map

Examine the National Geographic map entitled "Living on the Edge" and answer the following questions:

1. Study the earthquake patterns along the **Cascadia Subduction Zone** in N. California, Oregon, and Washington. Describe the area that has had the largest number of earthquakes; area of the least?
THE MENDOCINO TRIPLE JUNCTION AREA OFF OF THE COAST OF NORTHERN CALIFORNIA HAS THE MOST EARTHQUAKES. NORTH COASTAL OREGON HAS HAD THE FEWEST.
2. In comparison to other subduction zones worldwide, the Cascadia Subduction Zone has a distinct lack of earthquakes. In fact, there has never been an instrumentally recorded earthquake on the boundary between the down-going Juan de Fuca plate and the overriding North America plate. What are two possible scenarios for motion between the Juan de Fuca and North America plates that would lead to a lack of earthquakes on the Cascadia Subduction Zone?
 - JUAN DE FUCA PLATE IS YOUNG AND PLIABLE, AND IS NOT PRONE TO EARTHQUAKES
 - THE INERTIA OF A SMALL PLATE IS NOT ENOUGH TO CAUSE EARTHQUAKES
 - THE JUAN DE FUCA RIDGE IS BEING PULLED TO THE NORTHWEST WITH THE PACIFIC PLATE, AND THERE IS LITTLE CONVERGENT MOVEMENT AT THE CASCADIA SUBDUCTION ZONE
 - THE YOUNG AGE OF THE JUAN DE FUCA PLATE RESULTS IN A WARM PLATE, THAT IS NOT READILY SUBDUCTED. IT IS LOCKED UNTIL ENOUGH CONVERGENCE OVERCOMES THIS BUOYANCY, AND THEN THERE WILL BE A BIG EARTHQUAKE TO RELIEVE STRAIN.
 - MINIMAL LENGTH OF CASCADIA SUBDUCTION ZONE (BETWEEN TRANSFORM BOUNDARIES OF THE SAN ANDREAS AND THE ALASKAN TRANSFORM ZONES) IN COMPARISON TO LENGTH OF MOST SUBDUCTION ZONES WORLDWIDE.
3. Read inset information on the map indicating that a large earthquake occurred in the geologic past along offshore Oregon. Are any of your reasons above consistent with this evidence? Explain.
PERHAPS THE FOURTH REASON. BUT MOST DO NOT EXPLAIN THE LARGE EARTHQUAKE IN 1700.

4. Using the Earth's Fractured Surface map, compare the Cascadia and Aleutian subduction zones and speculate on why they have such different earthquake activity.

- THE CASCADIA ZONE IS BENEATH CONTINENTAL CRUST; THE ALEUTIAN IS BENEATH OCEANIC.
- SMALL SIZE OF JUAN DE FUCA PLATE DOES NOT HAVE THE INERTIA OF THE PACIFIC PLATE AT THE ALEUTIANS
- AGE OF JUAN DE FUCA PLATE CONTRIBUTES TO PLIABILITY, BUOYANCY.

5. Read the information on the map about the Cascade volcanoes.

Would you consider the Cascades to be active volcanoes? Explain.

SINCE MT. ST. HELENS IS ACTIVELY ERUPTING **NOW**, THEY SEEM PRETTY ACTIVE. MT. SHASTA ERUPTS ON AVERAGE EACH 600 YEARS, AND IT ERUPTED ABOUT 300 YEARS AGO. THEY ARE ACTIVE.

6. Locate Long Valley Caldera in eastern California, and suggest a reason why there have been such a large number of earthquakes in this region. (HINT: Note that Mt. St. Helens shows a similar cluster of earthquakes).

IT IS LIKELY THERE IS MAGMA BENEATH THE LONG VALLEY CALDERA AREA. A VOLCANIC ERUPTION MAY BE IMMINENT.

Part C – Studying the San Andreas Fault, California

Study Figure 1 on the following page and answer the following questions.

1. Put arrows **on Figure 1** along opposite sides of the San Andreas Fault to show the relative sense of movement along the San Andreas Fault. What kind of **plate boundary** is the San Andreas Fault? **TRANSFORM**
2. It is possible to estimate the average annual rate of movement along the San Andreas Fault by recognizing rocks older than the fault that have been offset by the fault. Note that Pliocene-Miocene (M) rocks have been cut and offset by the fault. These rocks have been dated as being 25 million years old. What is the average annual rate of fault movement in centimeters per year (cm/yr)? Show all your work, including units.

$$8 \text{ cm map distance} \times \frac{200\text{km}}{4\text{cm}} = 355\text{km distance}$$

$$355\text{km} \times \frac{1000\text{m}}{1\text{km}} \times \frac{100\text{cm}}{1\text{m}} = 35500000\text{cm} \qquad \frac{35500000\text{cm}}{25000000\text{yr}} = 4.44\text{cm/yr}$$

3. The average yearly rate of movement on the San Andreas Fault is very small. Does this mean that the residents of southern California are safe from earthquake damage caused by earthquakes on this fault? Explain. **THE FAULT MOVES IN LARGE JUMPS AT LESS FREQUENT INTERVALS THAN ONE YEAR.**

An average movement of about 5 meters along the San Andreas Fault was associated with the 1906 San Francisco earthquake. Assuming that all of the displacement along the San Andreas Fault over the last 25 million years was produced by earthquakes with 5 meters of displacement, calculate the average recurrence interval (number of years between earthquakes) for these earthquakes. Show all your work, including units.

$$355\text{km} \times \frac{1000\text{m}}{1\text{km}} = 355000\text{m} \qquad 355000\text{m} \times \frac{1\text{quake}}{5\text{m}} = 71000\text{quakes}$$

$$\frac{25000000\text{years}}{71000\text{quakes}} = 352.11\text{years between earthquakes}$$

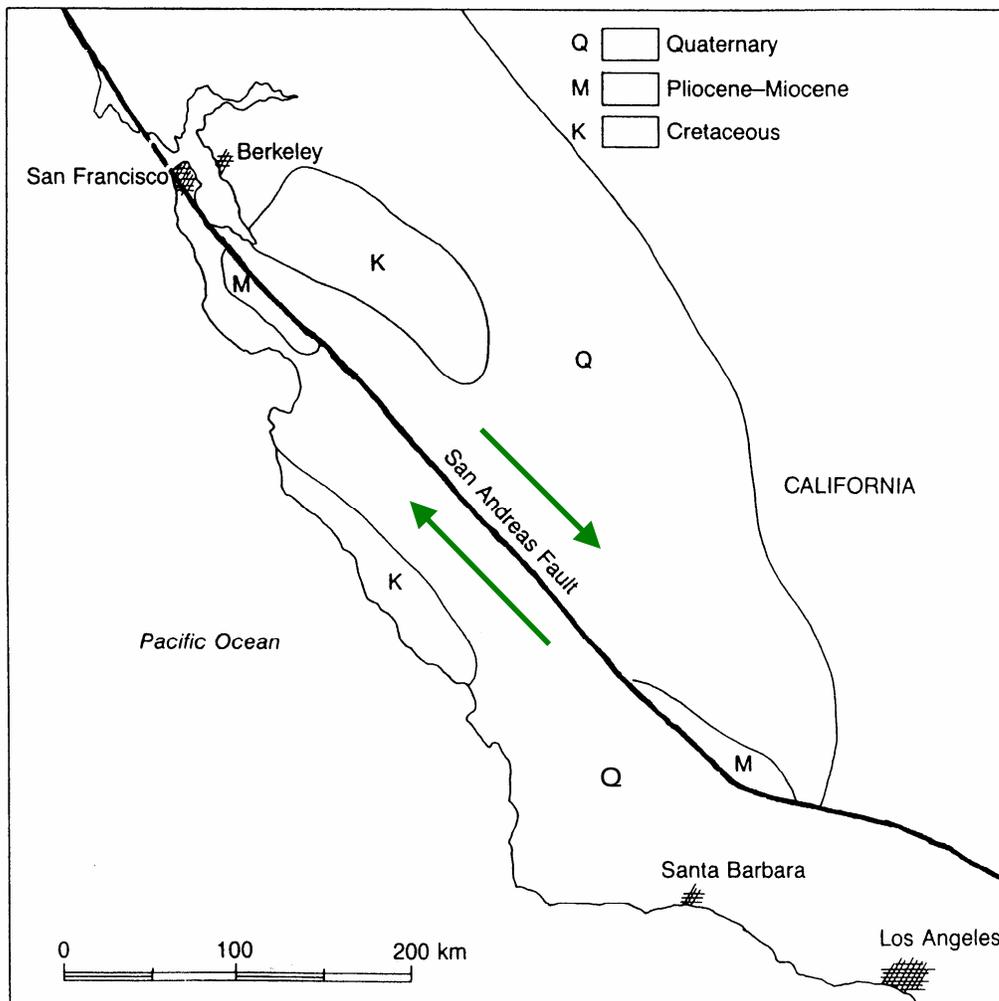


Figure 1: Generalized geologic map of southern California showing the San Andreas Fault.

Name _____ **KEY** _____
Lab day _____ Lab Time _____

Post Lab Assessment

1. Today, we can directly measure motion of the plates using Global Position System. How does the plate motion rate measured using GPS differ from the plate motion rates that you calculated using hotspot tracks? What does the fact that the GPS rates and hotspot track rates generally agree with each other tell you about plate motions over long time periods?

GPS MEASURES THE ACTUAL MOVEMENT PER YEAR, INSTEAD OF AVERAGE MOVEMENT OVER MILLIONS OF YEARS. SINCE THESE ARE IN GENERAL AGREEMENT, THE PLATE MOTION IS CONSISTENT OVER TIME.

2. Suppose the Earth's tectonic engine ground to a halt. What would be the implications for the geologic phenomena that you examined in the lab today? Be sure to justify your predictions fully.

THE MOUNTAINS WOULD BE WORN DOWN TO THE SEA. NO MORE VOLCANOES ALONG CONVERGENT BOUNDARIES. HOTSPOT VOLCANOES WOULD BECOME ENORMOUS.